**Article title:**

20th century seasonal moisture balance in Southeast Asian montane forests from tree cellulose δ¹⁸O

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Electronic Supplementary Material

**Online Resource 1.** a) A hill shade map of Mainland Southeast Asia, created from 90m digital elevation data (Jarvis et al. 2008). b) Climatology of five-day mean precipitation and temperature from the nearest meteorological station Chiang Mai, calculated from daily observations from 1951 to 2006.

![Hill shade map and climatology graph](image)

**Online Resource 2.** Tree ring sampling and processing

Six cores from six different trees were analyzed in this study. All cores were around 100 years old, but only from the 1920s to 2000 were precisely dated. Cross-dating took place in the Tree Ring Lab at Lamont-Doherty Earth Observatory. Unlike most tropical tree species, the conifer *P. kesiya* develops a clear annual ring structure. Each annual ring consists of two visibly distinct sections, white early wood composed of large, less dense cells, and dark late wood composed of smaller, denser cells. The color of the wood changes gradually from the early wood
to the late wood within a ring, but there is a sharp ring boundary between late wood and the following year’s early wood. For this study each core was sectioned subannually parallel to the ring boundaries using a microtome under a microscope. Slices were typically at 35 μm intervals, and every 3 full slices were combined into a 2 ml polypropylene centrifuge tube for cellulose extraction. In this manner, up to 20 samples were generated from a single ring. Alpha-cellulose was extracted from whole wood samples using a modified Brendel method (Gaudinski et al. 2005). Each cellulose sample used for isotopic measurement was weighed and wrapped in silver capsules and loaded into a Thermo Finnigan TC/EA for pyrolysis at 1420ºC. The CO product was then transferred online to a Delta V Advantage isotope ratio mass spectrometer via a purified helium stream. The isotope ratio (C\textsuperscript{18}O/C\textsuperscript{16}O) of each sample was measured and compared to a high purity CO standard. The sample C\textsuperscript{18}O/C\textsuperscript{16}O values were reported in standard δ notation with respect to vSMOW. Two standards were analyzed along with the samples, IAEA cellulose (IAEA-CH-3) and sucrose (IAEA-CH-6) standards (e.g. two standards with every twelve tree cellulose samples). Over the course of this study the analytical precision of the standards was 0.3‰.

**Online Resource 3. Tree cellulose oxygen isotope model**

The oxygen isotopic composition of tree cellulose primarily reflects that of the soil moisture and the humidity. Water and carbon dioxide are the two major reactants involved in the photosynthesis of cellulose. However, the oxygen originating from CO\textsubscript{2} undergoes complete isotopic exchange with tree H\textsubscript{2}O before carbohydrate synthesis (Deniro and Epstein 1979). The soil water is taken up by the tree roots with no isotopic fractionation. The water is then transported through the trunk to the leaves where a fraction of the leaf water is subject to evaporation and isotopic enrichment, which is governed by the relative humidity of the ambient
environment and to a lesser extent wind stress across the leaf surface (Roden et al. 2000).

Sucrose is produced in the leaves and then transported to the trunk where some oxygen atoms from sucrose undergo isotopic exchange with xylem water, which has the same isotopic signature as the source water. The sucrose is eventually consumed in the production of cellulose. The resulting cellulose oxygen isotopic ratio is expressed as (Sternberg 2009),

\[ \delta^{18}O_c = (\delta^{18}O_s + \varepsilon_a) + f (1 - \phi_o)(1 - h)(\varepsilon_e + \varepsilon_k) \]

where

- \( \delta^{18}O_c \) is the oxygen isotopic ratio of tree ring cellulose;
- \( \delta^{18}O_s \) is the oxygen isotopic ratio of soil water;
- \( \varepsilon_a \) is the biochemical autotrophic fractionation for oxygen isotopes, 27‰;
- \( f \) is the faction of leaf water that is subject to evaporation;
- \( \phi_o \) is the fraction of oxygen atoms in sucrose that undergoes exchange with xylem water;
- \( h \) is relative humidity;
- \( \varepsilon_e \) and \( \varepsilon_k \) are equilibrium and kinetic fractionation factors for water liquid-vapor phase change, respectively.

The first term on the right side of the equation describes the isotopic influence of soil water on the cellulose isotopic composition. The second term represents evaporative isotopic enrichment in the leaf associated with the relative humidity.

**Online Resource 4.** Correlation coefficients and p-values between Doi Chiang Dao cellulose \( \delta^{18}O \) annual mean and the following: Doi Chiang Dao precipitation, represented by the nearest grid point (19.25 °N, 98.75 °E) of GPCC V4 0.5 degree precipitation (Rudolf et al. 2005; Rudolf et al. 2003); Mainland Southeast Asia (MSEA) precipitation, an area-weighted GPCC
precipitation over the region of 10-25 °N, 95-110 °E; and All India Rainfall (AIR) (Parthasarathy et al. 1994). In bold are the strongest correlations.

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<th>MSEA precipitation</th>
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**Online Resource 5.** Relative humidity (red) for the dry season November to April at the nearest meteorological station Chiang Mai, and the November to April Parmer Drought Severity Index (UCAR PDSI) for the region of 18-20 °N, 98-100 °E.

References

Rudolf B, Beck C, Grieser J, Schneider U (2005) Global precipitation analysis products. Global Precipitation Climatology Centre (GPCC), DWD, Internet publication, 1-8,